The Memoirs of Faculty of Engineering
Fukuyama University
The 11th issue, 1989

$LiTaO_3$ Waveguide Optical Gate for Observation of Time-Domain Optical Pulse

Hiroya Sano*, Ryuzi Koga**, Megumi Kosaka**

ABSTRACT

An optical signal can be switched with a time resolution down to picosecond order by Auston switch which is controlled by several branched gates formed on $LiTaO_3$ substrate.

This paper explains on a measuring principle, a developing progress for the fabrication process of a waveguide switch on $LiTaO_3$ substrate, and a total system composition.

Key Word : Integration of Sensing Lightwave Circuit

I. Introduction

Most of the fundamental optical communication techniques have been already solved. However a desire to improve a bit rate on a propagating velocity of communication is still deep and techniques to generate and control an optical pulse width of 10ps order will be practiced in the near future.

The basic methods for the observation of a optical waveform of this very short pulse have become already possible theortically, but many problems have been left in this method for a practical use.

A correlation method is easy in treatment and makes a high time resolution possible, but may not theoretically realize the correct observation of a single optical pulse waveform.

On the other hand a streak camera has a satisfactory performance for this purpose, though the handling is troublesome by a big and complicated structure.[1) 2)]

The authors have already succeeded in the observation of a single pulse waveform of 500ps with a high time resolution.[3) 4)] In this method an bulk type pockle's cell was used as an optical gate, and an optical fiber, as a delay line.

Furthermore the improvement of this resolving power required larger energy than available. An integrated system on a $LiTaO_3$ substrate may reduce an optical energy level needed for the observation of a waveform, and a small geometrical dimension may improve a time resolution by this measurement.

The authors have developed a process for fabricating optical waveguide,[5)] a pattern design for the optimal timing, and coupling method of the gates to external optical fibers.

* Department of Electronic & Electrical Engineering ** Okayanma University

II. Principle of the observation of optical real time waveform

When a time domain waveform, f(t) is a single optical pulse wave, an equation

$$F(\tau)=\int_{-\infty}^{\infty} F(\tau)\,\delta(t-\tau)\,dt=-\int_{0}^{\infty} f(t+\tau)\,dt \qquad (1)$$

is given,

where

$$f(t)=d/dt\cdot F(t) \qquad (2)$$

The middle term of eq. (1) is a sampling value of time function of F(t) at $t=\tau$.

Obviously the results are as same as the inner products for a value at time delay, τ , and step function, if a derivative function of F(t) is known as shown in Fig.1.

Fig.1 illustrates these principles. The product of time shift by step function is obtained by controlling propagating time of a signal through guided optical gates.

The integration concerning time is an integrated value of a radiated light power to a photo diode. Therefore this relation is obtained by principle that optical energy proportions to an output charges.

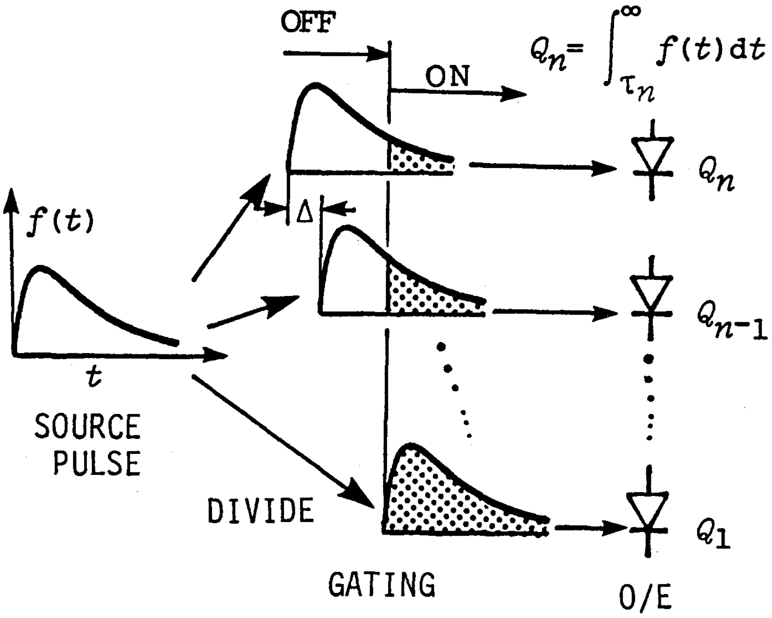

Fig.1 Observation principle for a single optical pulse waveform

Fig.2 is a system fabrication on which the principles mentioned above are applied to a bulk type element.

Each different delay time of an optical signal is introduced by use of a bunch of multiple optical fibers with different length each. For the branch of a optical signal a bitapered star coupler which makes of multiple optical fibers fused into one and twisted was used. The side surfaces of these optical fiber's edges are aligned neatly, and the surface is butted together to a rod lens of $\lambda/4$ type.

Optical beams are designed so as to be projected from each fibers without overlapping each other, converging on to a main optical axis by a lens.

A small Pockle's cell, 1mm long, 1mm wide, which is put near the waist of the beam-bundle achieves a common gate action to every beam. Electrical field is applied perpendicular to the optical axis. A controlling electrical signal is generated by silicon Auston switch placed in contact with this Poc-

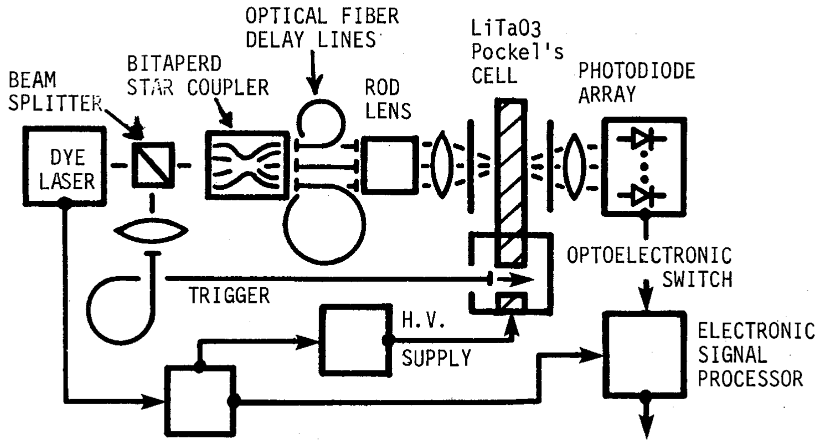

Fig.2 Observation system for a single optical pulse by individual element

kle's cell.

The electrical signal propagate along the electrodes on the sides of the crystal. Optical beams which propagate through the Pockle's cell are transformed into electrical signals by photoelectric effect of is photo-diodes which are prepared for each optical channel. In conclusion, an integrated value of optical signal power, that is, electrical charges proportional to its energy, are generated.

An electrical signal processing system is connected to on each channel. The difference values which is the approximation of equation (2) are obtained from the outputs of the neighboring channels.

Fig.3 is an example of experimental results obtained by a trial system which has twelve optical channels. An optical source is generated from a dye laser pumped by a nitrogen laser.

As this optical waveform hardly changed on a relative delay between an optical signal and optical trigger, it is believed that the correct waveform of a laser optical pulse could be observed by this measuring method.

Improvement of time resolution and S/N ratio are inconsistent with each other. It is believed that the inconsistency is caused for a radiated optical energy from laser by the reason which will be discussed below.

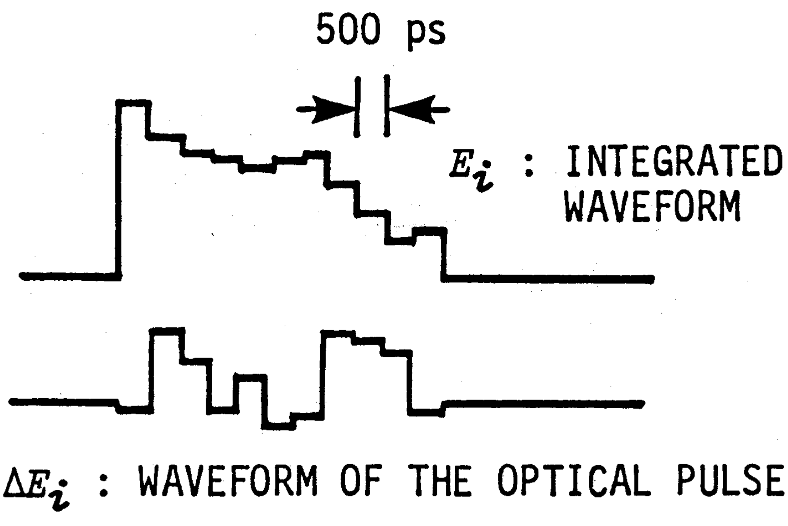

Fig.3 Observed waveform of laser pulse gained by individual element

That is, an optical fiber length difference must get as shorter as possible for the improvement of time resolving power, but on the contrary, a radiated laser energy gets less as it becomes shorter.

A limit of manual cutting of fiber is thought to be about 10mm long empirically. This length influences optical waveform resolving power seriously. Equivalent time of this limit of length difference influenced to this accuracy is almost equivalent to 50ps.

It is thought that integration of this optical system is the best method for the improvement of this resolving power.

Ⅲ. Formation of optical wave guide on $LiTaO_3$ substrate

The authors had investigated the channel type by diffusion and ridge type wave guide should be better for our purpose.

Smoothness of the substrate has a great influence on a success of the forming process. As a surface of the board can not be smoothed by our present manufacturing equipments, the inevitable energy loss on the surface is foreseen for ridge type. Therefore the authors adopted an buried type processed by diffusion process.

Diffusion temperature for this type must be maintained under Curie temperature so that polarizing characteristics of $LiTaO_3$ necessary to optical gate action do not deteriorate. So the authors used Cu which makes possible to diffuse at low temperature as depart for a control of reactive index.

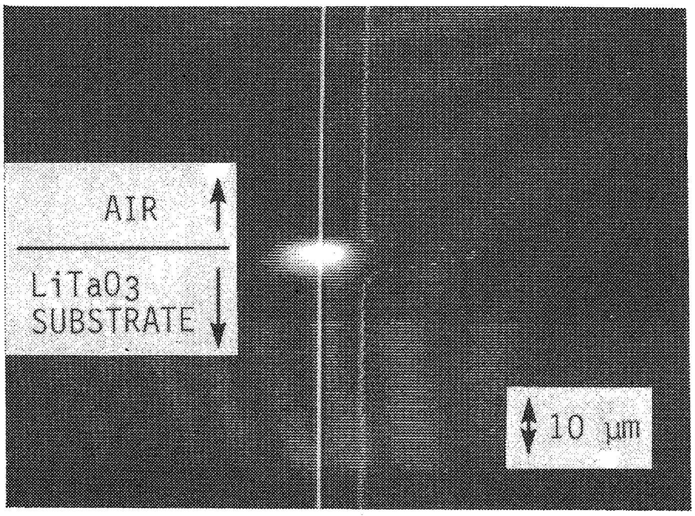

Fig.4 A photograph of a near-field pattern of waveguide made by heat diffusion

Table 1 shows a process of the formation of optical wave guide. Before this was found, Cu was sputtered on the substrate. After that it is diffused by heat in an atmosphere of non-active gas. As a result the defects which cause for a loss in oxygen atoms appears. Then, CuO is chosen as a donor of Cu in order that the diffusion by heat is done in an atmosphere of air.

Table 1 Forming process of optical waveguide on $LiTaO_3$ foundation board

NO	NAME OF PROCESS	NOTE
1	patterning	positive type resist. OFPR 800
2	high hrequency spattering of Cu	7 nm
3	lift-off	supersonic washing by aceton
4	spattering for a protecting film	corning glass 7059, 93 nm
5	heat diffusion	air circumstance, 45℃ 12 hours
6	washing	phosphoric acid, heating & boiling,protecting film basking
7	grinding	edge forming of waveguide
8	washing	phosphoric acid, heating & boiling

It is calculated that they must be about 10μm wide so that a wave guide be single mode.

We adopted a lift-off method as a provisional means, and a narrow width is made by a blur of edge.

Now we have succeeded to develop a negative mask system enough to get satisfactory solution ability.

On our fabrication process, glass (Corning No. 7059) is sputtered on cup after patterning on a process (4) of Table 1 as protecting film. After that a heating process is practiced on a process (7). The protecting film of the surface is absolutely necessary to keep the wave guide stable after many weeks. But causes of the deterioration have not been explained yet.

Fig.4 is a photograph of a near-field pattern when a light of He-Ne laser was radiated on wave guide which we made.

IV. Integrated optical waveguide

There are several steps in the development of integrated optical waveguide.

First the authors studied on a waveguide type gate for the purpose of making an optical signal energy necessary to measure as smaller optical wave as possible. Fig.5 is a pattern of gate part in a system of waveguide type optical gate. Four gates are made on a $LiTaO_3$ substrate as shown in this figure.

The voltage wave driven by a silicon Auston switch is applied to the strip line as a control signal, and each gate is turned to on-state from the off each after each.

In an optical gate an optical waveguide has an electrode branched in Y shape divided into two equal parts. When a controlling electrical field is applied, optical signal is diverged into a branched waveguide at this cross point. The velocity of controlling electrical signal of strip and group velocity of the optical signal are about 1/5.2 and 1/2.2 to ones in vacuum, respectively. This difference adjusts the time difference τ_n described in 2.

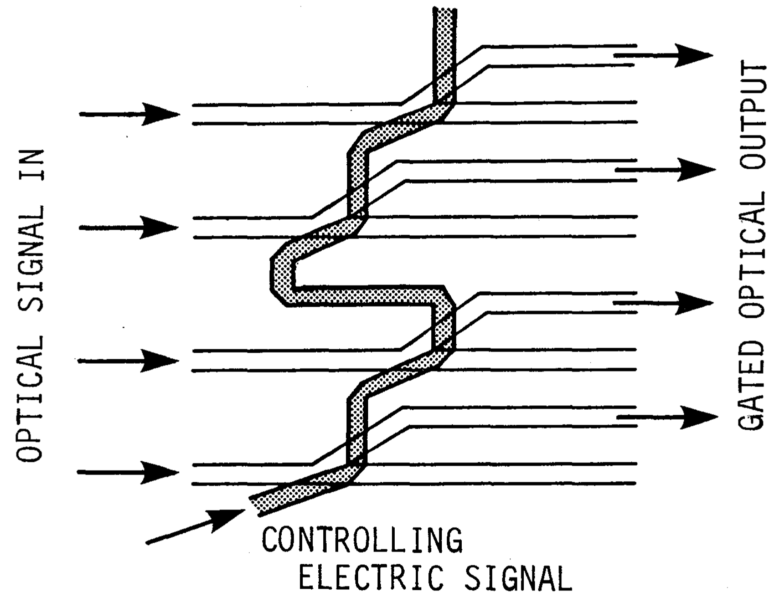

Fig.5 Waveguide switch group which controls a delay time

Fig.6 shows a Si substrate which enables the connection of an integrated optical guide wave switch with multiple optical fiber. Si substrate (100) is etched in some various diretions to connect a wave guide on $LiTaO_3$ substrate with optical fibers. By gate action an optical pulse is guided to a photo diode through an optical fiber of each channels. Thus an optical signal is changed into an electrical signal.

If four sheets of this substrate are arranged in parallel, sixteen channels obtained. After all, optical pulse wave is reproduced from the output of a diode through an analog computer circuit.

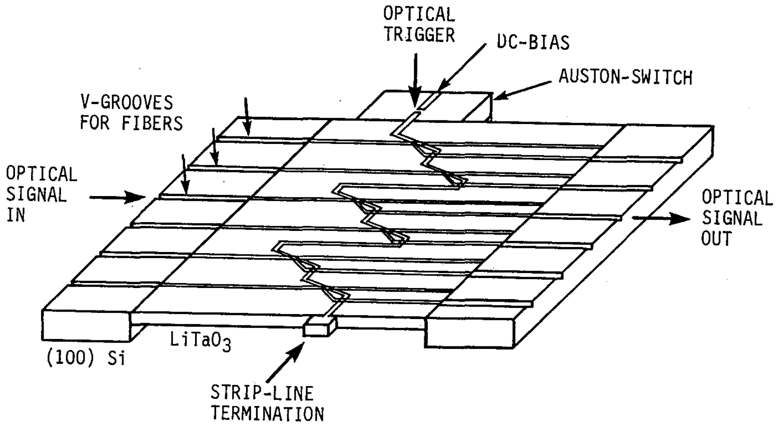

Fig.6 Integrated optical waveguide switch and Si substrate on which V-grooves are engraved for optical fibers

V. Conclusion

The authors have developed an observation system of single optical pulse waveform which consists of many kinds of optical elements. This paper reports about a fabricating process of the system and frame of the system empirically.

Our research will be carried out about detailed designs of a process for the integration and connection of external circuits, hereafter.

References

1) E.P.Open & C.V.Shank., "Ultrashort Light Pulse, (S.L.Shipper Ed.)", Springer-Verlag (1977) 83

2) D.J.Broadly & W.Sabot., Apple.Pays.Letter, 27 (1975) 382.

3) H.Codger, M.Ebara, M.Corsica & H.Sand., "Single-shot Subnanosecond Light-Pulse Waveform Monitoring by an Optical Circuit", Transact., Inst. Electron. Communication End., J64-C (1981)258.

4) R.Codger, M.Corsica, & H.Sand., "Single-Shot Subnanosecond Light-Pulse Waveform Monitoring and Optical Circuit---Improvement and Estimation for the Performance---", Traps.Inst.Electron. Comb. End., Japan, J68-C (1985) 973.

5) R.Codger, M.Corsica & H.Sand., "Research Report of the Special Project Research on "Lightwave Sensing",the Grant-in-Aid by the Ministry of Education, Science and Culture, Japan, (1987) 62.